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OVERVIEW OF EPA'S LIMB TECHNOLOGY DEVELOPMENT PROGRAM

by

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15. SUPPLEMENTARY NOTES Author Lachapelle's Mail Drop is 63; his phone is 919/541-3444.

16. ABSTRACT The paper gives an overview of EPA's Limestone Injection with Multistage Burners (LIMB) program, a program for research, development, and demonstration of cost-effective emissions control technology for coal-fired boilers that can reduce both sulfur oxides (SOx) and nitrogen oxides (NOx). The LIMB concept uses low-NOx burners plus sorbent injection to control these pollutants simultaneously. LIMB technology represents a lower cost alternative to currently available SOx control approaches such as flue gas desulfurization, coal cleaning, and coal switching. LIMB technology is especially attractive where coal-fired boilers must be retrofitted to minimize emissions of NOx and SOx, which are major acid rain precursors. This is due to LIMB's relative ease of retrofit to both small and large coal-fired boilers and its lower cost. LIMB performance goals are: (for retrofit) to achieve a 50-60% reduction of both SOx and NOx from uncontrolled levels; and (for new units) to achieve a 70-80% reduction of NOx and a 70-90% reduction of SOx from uncontrolled levels.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field Group
Pollution	Pollution Control	13B
Nitrogen Oxides	Stationary Sources	13A
Boilers	LIMB Program	08G
Limestone	Low-NOx Burners	21D
Coal	Sorbent Injection	21B
Combustion		07B
Sulfur Oxides		

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INTRODUCTION

LIMB is EPA's acronym for Limestone Injection with Multistage Burners. It is EPA's program for research, development, and demonstration of cost-effective emissions control technology for coal-fired boilers that can reduce both sulfur oxides (SO_x) and nitrogen oxides (NO_x). The LIMB concept uses low-NO_x burners plus sorbent injection to simultaneously control these pollutants. LIMB technology represents a lower cost alternative to currently available SO_x control approaches such as flue gas desulfurization, coal cleaning, and coal switching.

LIMB technology is especially attractive where coal-fired boilers must be retrofit to minimize emissions of NO_x and SO_x, which are major acid rain precursors. This is due to LIMB's relative ease of retrofit to both small and large coal-fired boilers and its lower cost.

LIMB performance goals are:

For retrofit: achieve a 50 to 60 percent reduction of both SO_x and NO_x from uncontrolled levels.

For new units: achieve a 70 to 80 percent reduction of NO_x and 70 to 90 percent reduction of SO_x from uncontrolled levels.

For both retrofit and new units: achieve these performance goals at total plant investment costs of at least $100/kW less than the major technology alternative, flue gas desulfurization.

The current LIMB program is structured to address the major technology areas requiring optimization to support an initial demonstration on a pulverized-coal wall-fired utility boiler. Major focus is on:

1. BASIC RESEARCH, and BENCH AND PILOT-SCALE DEVELOPMENT in support of LIMB.

2. PROTOTYPE TESTING of LIMB Technology.

3. PROCESS ANALYSIS and WALL-FIRED DEMONSTRATION.

Currently, emphasis is being placed on increasing the applicability of retrofits to an existing boiler population that does not have NO_x and SO_x controls. Additionally, the program is focusing on new boilers where increased design flexibility could give the potential for higher NO_x and SO_x control levels. A brief description of each program area follows.

BASIC RESEARCH, AND BENCH AND PILOT-SCALE DEVELOPMENT

This program area consists of in-house and extramural activities that will provide the basic understanding of the controlling phenomena that is essential for success. These activities will develop information on the fundamentals of sorbent-reaction chemistry, establish scale-up parameters for LIMB, and support the LIMB demonstration. Three major goals of this program area are:

- Development of methods for generation and/or injection of high surface area super-active sorbents which have the potential for highly efficient SO_x capture and improved LIMB cost effectiveness.

- Provide an understanding of the effects of interactions between sorbent and coal mineral matter and activity promotors such as Na_2CO_3. These interactions are of paramount importance because they affect sorbent performance and boiler operation from slagging, fouling, and particulate collection standpoints.

- Evaluation of the feasibility of further reducing LIMB operating costs through recycle of partially spent sorbent and/or re-use of the sorbent/ash mixture.

PROTOTYPE TESTING OF LIMB TECHNOLOGY

This extramural program area is structured to provide industry with performance evaluation of low-NO_x burners with sorbent injection. These detailed evaluations will further increase industry's confidence in LIMB technology and will establish the technically achievable SO_x/NO_x levels for use by decision makers. Further, activities in these areas will provide the initial burner and sorbent injection system design required for the LIMB demonstration. Three major goals of this program area are:

- Provide scale-up criteria for use of conventional and super-active sorbents in a large (100×10^6 Btu/hr)* experimental facility that simulates the flow patterns and thermal gradients of typical wall-fired furnaces.

- Extend scale-up criteria for sorbent injector configurations, locations, etc., to support a planned demonstration of LIMB technology on a tangentially coal-fired utility boiler. This systematic study will utilize cold flow modeling plus combustion tests on a large experimental facility (25 to 100×10^6 Btu/hr) that simulates the unique flow patterns of this furnace.

* For those more familiar with metric units, see conversion table at the end of this paper.

- Provide support to a cooperative program for evaluating LIMB on a small (20 to 40 MWe) boiler. This effort augments the work performed in experimental facilities because it considers critical boiler-related conditions such as slagging and fouling, convective pass residence time and tube spacing, air heater and particulate control system performance, and ash disposal systems.

PROCESS ANALYSIS AND WALL-FIRED BOILER DEMONSTRATION

This extramural program area provides design and engineering criteria for applying LIMB technology to existing wall- and tangentially fired utility boilers. It provides the basis for cost/benefit analyses and extends the applicability of the technology. It supports the planned demonstration projects. Four major goals of this program area are:

- Synthesize and generalize the critical design, engineering, and economic criteria into an integrated form available for ensuring maximum success and widest applicability of LIMB technology.

- Demonstrate that a 50 to 60 percent reduction of both SO_x and NO_x can be achieved by retrofitting LIMB technology on a wall-fired utility boiler.

- Demonstrate that a 50 to 60 percent reduction of both SO_x and NO_x can be achieved by retrofitting LIMB technology on a tangentially fired utility boiler.

- Provide and support efficient and timely transfer of the latest research, development, and demonstration information to Congress, industrial users, and the engineering and research communities.

BACKGROUND

The use of sorbents to control emissions of SO_x from coal-fired power plants is not a new concept. It was evaluated most extensively during the period 1968 to 1971. Results from these early demonstration studies showed poor SO_2 removal efficiencies, typically in the range of 10 to 40 percent using limestone and dolomite. These unfavorable results prompted abandonment of dry sorbent injection as a SO_2 control technique. Flue gas desulfurization ultimately became the SO_2 control method of choice. Recently, the potential of the sorbent injection process has been re-examined principally because of 1) a need to develop low cost SO_2 control technology for acid rain control strategies, 2) pilot-scale tests that indicated that significantly higher SO_2 capture could be achieved at reasonable alkali to

sulfur ratios, and 3) an improved understanding of the critical process variables that affect sorbent performance.

In late 1980, EPA's LIMB program was initiated with a goal of demonstrating the process in 1987. Since its initiation, the LIMB program has systematically focused on the critical process parameters that require resolution to ensure a successful demonstration. These encompass the full range of sorbent/fuel/boiler related considerations illustrated in Table 1. It is beyond the scope of this paper to discuss these in detail. Suffice it to say that these and other parameters are being systematically evaluated in EPA's program.

The chemistry of sorbent injection is globally straightforward. A sorbent (e.g., limestone) is flash-calcined to lime and subsequently reacts with SO_2 in the presence of O_2 to form $CaSO_4$. The overall reaction is represented as:

$$CaCO_3 + \text{heat} \rightarrow CaO + CO_2$$

$$CaO + SO_2 + 1/2\ O_2 \rightarrow CaSO_4$$

The sulfation window (i.e., the temperature regime where the sulfate is formed) is currently felt to be between 2250°F and 1650°F. This suggests that the sorbent might be injected some-

TABLE 1. LIMB PROGRAM RESEARCH CONSIDERATIONS

Sorbent	Fuel	Boiler
° Type	° Low to high sulfur	° Type (wall and tangentially fired)
° Chemistry	° Subbituminous to bituminous	° Injection methods and locations
° Activation	° Ash interactions	° Time/temperature requirements
° Surface activity		° Heat transfer
° Particle size		° Slagging/fouling
° Promotors		° Operability
° Sulfation		° Waste disposal
° Deactivation		° Scale-up and generalization
° Regeneration		° Economics

where just above the furnace outlet plane and ahead of the pendant superheaters. A schematic of a LIMB system is shown in Figure 1. Supplemental SO_2 removal to achieve new source performance standard control levels (up to 90 percent) could be obtained using a spray dryer module following the LIMB system.

TYPICAL SORBENT PERFORMANCE

EPA's LIMB program is evaluating a wide range of potential sorbents. Pilot-scale data for three different sorbents are shown in Figure 2. These results were obtained on a 1×10^6 Btu/hr experimental combustion facility firing an Indiana coal with 2.3 percent sulfur. The performance results for limestone, calcium hydroxide, and pressure-hydrated dolomitic lime correspond quite well with the specific surface area of these sorbents as follows:

$CaCO_3$: 5 to 15 m^2/g

$Ca(OH)_2$: 20 to 30 m^2/g

$Ca(OH)_2 \cdot Mg(OH)_2$: 35 to 45 m^2/g

The thermal environment and residence time of the sorbent in the sulfation window for these test results is representative of that which is expected to occur in boilers for which LIMB has

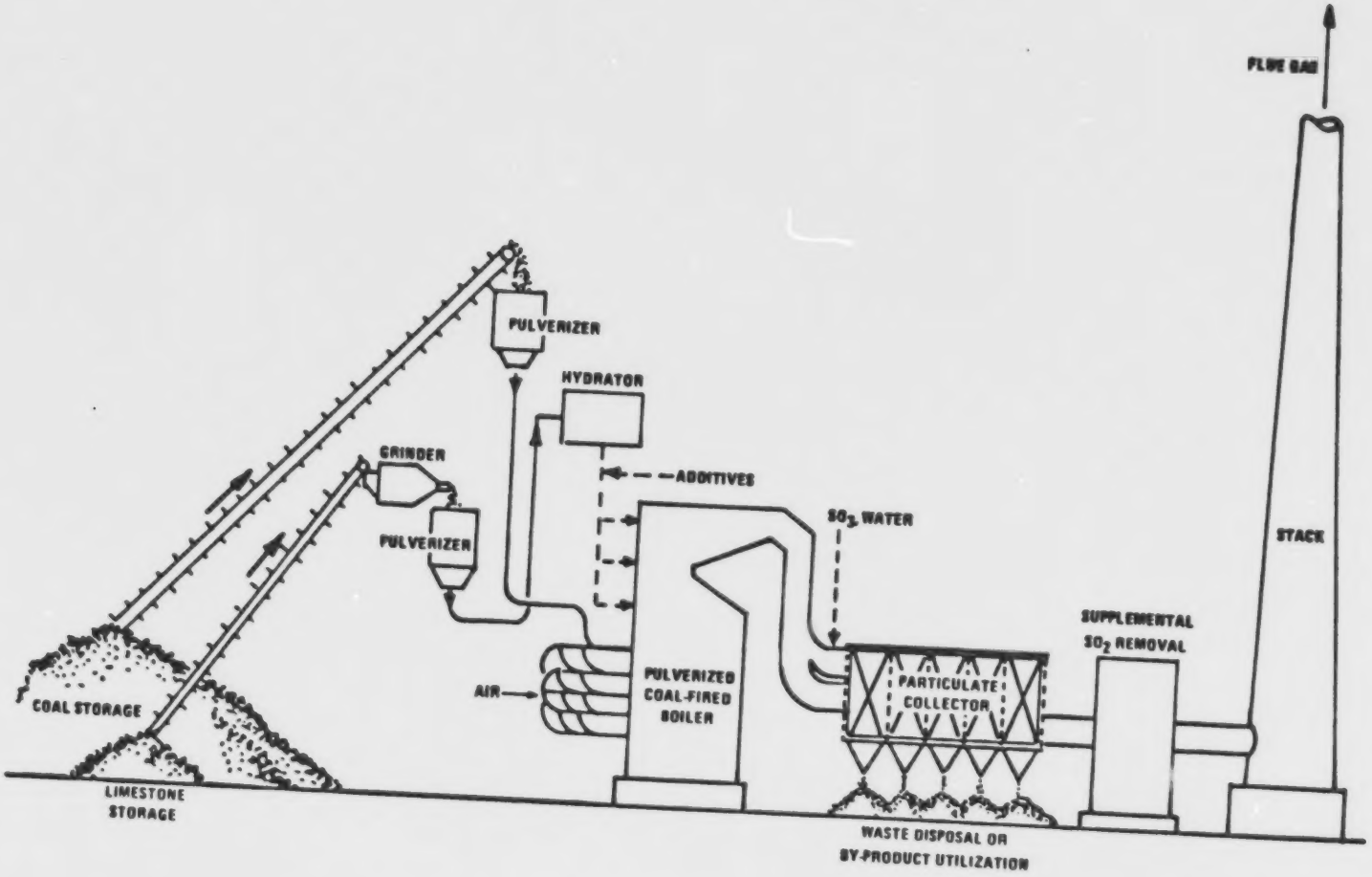

Figure 1. Schematic of integrated LIMB system.

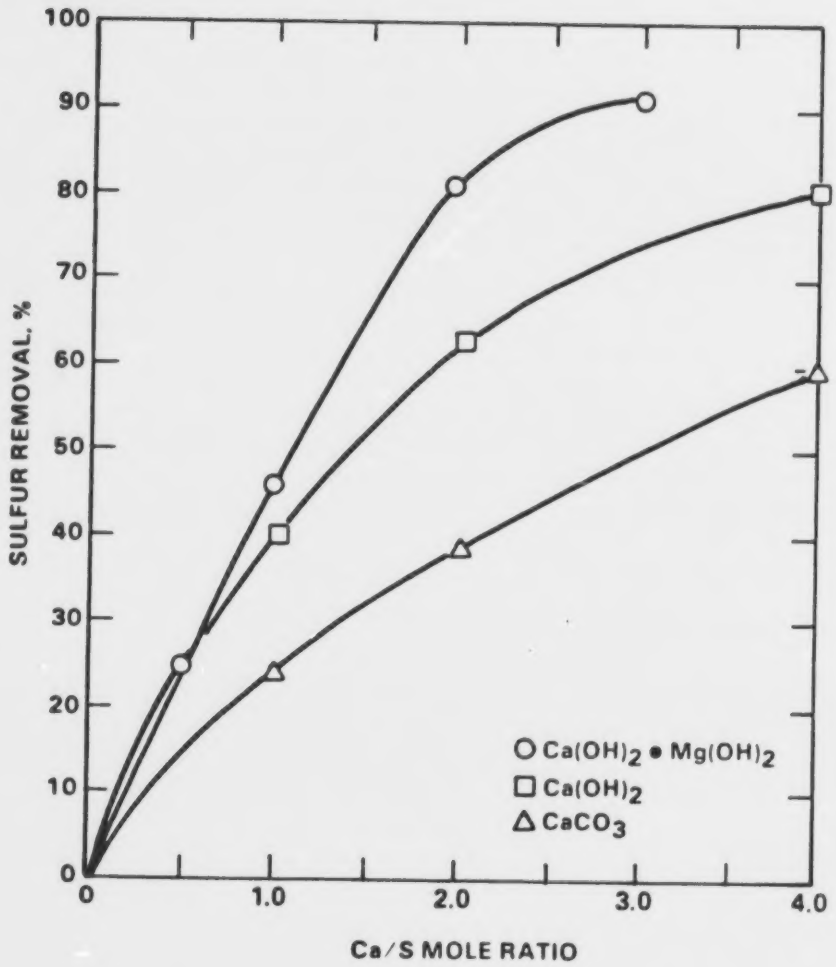

Figure 2. Typical sorbent performance.

applicability. Residence time calculations for typical U.S. boilers indicate that sulfation window residence times of 0.9 to 1.2 seconds are typically available. With proper mixing of sorbent and flue gases, these times should be adequate to yield the performance levels shown. The improved performance of the higher surface area sorbents has caused us to focus on these as potential candidates for use with LIMB. Experimental programs are on-going to study these in detail and to evaluate the overall economics of these sorbents since they are more expensive than conventional limestone.

Another area that shows promise in terms of improved performance is with the use of promoters. These are mineral substances that can be added in relatively small amounts to the sorbent to enhance its sulfur capture potential. Some very preliminary work conducted in the LIMB program indicates that the use of a promoter such as sodium carbonate can increase limestone and $Ca(OH)_2$ performance by about 1.4 times that typical of the unpromoted sorbents.

COMPARATIVE COSTS OF SO_2 CONTROL TECHNOLOGIES

LIMB technology offers economic advantages over conventional wet flue gas desulfurization (FGD) methods when moderate SO_2 control levels (45 to 65 percent) are required. The costs of these SO_2 control technologies have recently been evaluated in considerable detail by EPA based on work conducted by TVA (1); Combustion Engineering, Inc. (2); PEDCo Environmental, Inc. (3), and in-house cost analysis work performed by AEERL.

Since the SO_2 removal efficiencies are different for LIMB and FGD, cost comparisons are presented on a normalized basis; i.e., cost per ton of SO_2 removal. The cost analysis procedures are based to the maximum extent possible on guidelines suggested by the Electric Power Research Institute (4). The current dollar analysis method is used with costs expressed in 1985 dollars. For retrofit units, 15-year levelized costs are used; whereas, 30-year levelized costs are used for new units. Internally consistent costs and/or factors for such items as operating and maintenance labor, maintenance material, administrative and support labor, consumables, and levelization factors have been employed to ensure that the LIMB and FGD costs are on an equivalent basis. Tables 2 and 3 present summaries of the major premises used in the economic analysis. In addition to those shown,

TABLE 2. MAJOR ECONOMIC PREMISES FOR COST OF CAPITAL

	New Units	Retrofit Units
Base year for cost comparison	1985	1985
Book life, years	30	15
Tax life, years	15	5
Inflation rate, %/yr	8.5	8.5
Debt/equity ratio	50/50	50/50
Debt cost, %/yr	11.0	11.0
Preferred stock ratio, %	15	15
Preferred stock cost, %/yr	11.5	11.5
Common stock ratio, %	35	35
Common stock cost, %/yr	15.3	15.3
Weighted cost of capital, %/yr	12.5	12.5
Federal plus state income tax rate, %	50	50
Property taxes and insurance, %/yr	2	2
Investment tax credit, %	10	10
Levelized carrying charge rate, %	15.3	16.01

TABLE 3. MAJOR ECONOMIC PREMISES FOR OPERATING AND MAINTENANCE COSTS

		New Units	Retrofit Units
Base year for cost comparison		1985	1985
Unit capacity factor, %		62.8	62.8
Book life, years		30	15
Tax life, years		15	5
Levelizing factor		2.314	1.714
Waste disposal cost, $/ton		7.66	7.66
Operating manhours/year			
	LIMB	43,800	43,800
	FGD	55,460	55,460
Average labor rate, $/hr		23.37	23.37
Limestone cost, $/ton[a]		17.88	17.88
Water, $/1000 gal.		0.77	0.77
Process steam, $/1000 lb		4.84	4.84
In-plant power, mills/kW•h		58	58
Coal cost, $/$10^6$ Btu		2.61	2.61

a. A variety of sorbents can be used with LIMB. Costs for alternate sorbents are indicated in Figures 3 and 4 and in Table 6.

other indirect charges and assumptions enter into this rather complex analysis; e.g., engineering and home office overhead (including fee), project and process contingencies, cost of general facilities, preproduction costs, inventory capital, and land. Some of these charges are based on a percentage of process capital cost, while others are computed based on specific site requirements, cost and quantities of consumables, allowance for funds during construction, etc. It is beyond the scope of this paper to discuss these in any depth, but we have ensured that most charges and assumptions are consistent within and between LIMB and FGD.

Table 4 gives some of the technology-related assumptions used in developing the costs for LIMB. For FGD, the assumption is that the design employs spray tower absorbers utilizing forced oxidation with landfill disposal of solid waste. The FGD system employs one spare absorber train for new units and none for retrofits. Emergency bypass of 50 percent of the flue gas normally scrubbed, and reheat to 175°F, is included.

For FGD systems, the stoichiometric ratio is defined as the moles of calcium per mole of SO_2 absorbed. For LIMB, the stoichiometric ratio is defined as the moles of calcium per mole of sulfur in the fuel. Typically, a stoichiometric ratio of 1.4 is used with

TABLE 4. TECHNOLOGY-RELATED ASSUMPTIONS FOR LIMB

Process Component	New Units	Retrofit Units
Sorbent injection system	✓	✓
Low-NO_x burner upgrades	a	b
Economizer upgrades	c	d
Sootblower upgrades	✓	✓
Particulate collector type:		
Electrostatic precipitator		e
Baghouse	f	
SO_3 conditioning		e
Dry waste disposal	✓	✓

a. New units are assumed to be already equipped with burners capable of meeting the current NO_x standard of 0.6 $lb/10^6$ Btu for bituminous coal and 0.5 $lb/10^6$ Btu for subbituminous coal.

b. Retrofit units are assumed to be backfit with improved burners capable of meeting NO_x emissions of 0.7 $lb/10^6$ Btu.

c. New units are assumed to be already equipped with a bare tube economizer.

d. Retrofit units are assumed to have an existing finned tube economizer which is replaced with a bare tube economizer.

e. Retrofit units have upgraded ESPs to handle the additional solids loading plus SO_3 conditioning to improve resistivity.

f. New units have baghouses which are not charged off as a LIMB-related cost.

FGD for 90 percent SO_2 control; whereas for LIMB, stoichiometric ratios of 1.4 to 2.5 might be employed depending on the sorbent and required control level. A LIMB system using a Ca/S ratio of 2 and achieving 50 percent SO_2 control would be equivalent to a stoichiometric ratio of about 4 using FGD's nomenclature for stoichiometric ratio. The figures in this paper that illustrate the comparative costs of LIMB and FGD use the stoichiometric ratio nomenclature associated with the respective technology: for LIMB, it is shown as Ca/S; for FGD, as Ca/SO_2.

Table 5 gives the boiler and coal characteristics used for the LIMB and FGD economic analysis. The unit sizes selected represent those typical of retrofit and new applications. Wall-fired designs were used in all cases. The coals encompass the sulfur content range targeted for application of these SO_2 control technologies. The net plant heat rate is used in the analysis to determine the required coal flow and corresponding sulfur and SO_2 mass flow rates.

Table 6 gives the sorbents, Ca/S ratios, and SO_2 control levels used in the LIMB economic analysis. The performance data are derived from Figure 2 and from in-house testing of promoted sorbents. The sorbent costs represent delivered costs to the power plant based on current estimates from sorbent suppliers.

TABLE 5. BOILER AND COAL CHARACTERISTICS SELECTED FOR LIMB AND FGD ECONOMIC ANALYSIS

Unit Size, MWe	Status	Net Plant Heat Rate, Btu/kW°h	Coal Characteristics		
			HHV, Btu/lb	%S	%Ash
300	Retrofit	9,500	11,700	3.36	15.14
300	Retrofit	9,500	11,700	1.92	15.08
500	New	9,500	11,700	1.92	15.08
500	New	10,500	8,200	0.48	6.3

NOTE: Wall-fired boilers are used in these case studies.

TABLE 6. LIMB SORBENTS AND PERFORMANCE DATA USED FOR LIMB ECONOMIC ANALYSIS

Sorbent	Sorbent Cost, $/ton	Retrofit		New	
		Ca/S	SO_2 Control, %	Ca/S	SO_2 Control, %
Vicron $CaCO_3$	18 [a]	2.5	45	-	-
Longview $Ca(OH)_2$	45	2.0	62	2.7	70
Longview $Ca(OH)_2$	45	-	-	4.0	82
Corson $Ca(OH)_2 \cdot Mg(OH)_2$	60	1.4	62	1.63	70 [b]
Corson $Ca(OH)_2 \cdot Mg(OH)_2$	60	-	-	2.1	82 [c]
Promoted $CaCO_3$	25	2.0	56	-	-
Promoted $Ca(OH)_2$	50	1.5	65	1.8	70 [b]
Promoted $Ca(OH)_2$	50	-	-	2.8	82 [c]

a. Actual cost used was $17.88/ton.

b. Minimum percent control required by NSPS for the 0.48% S coal.

c. Minimum percent control required by NSPS for the 1.92% S coal to be at or below 0.6 $lb/10^6$ Btu.

The selection of these specific Ca/S ratios and corresponding SO_2 control levels resulted from an initial sensitivity and optimization study in which a range of Ca/S ratios and SO_2 control levels were evaluated. The values selected represent the optimum economic levels for these sorbents.

For retrofit units, the Ca/S ratio set the SO_2 control level. For new units, required SO_2 control levels to meet New Source Performance Standards were determined for the coals being used, which in turn set the Ca/S ratios.

Figure 3 and Table 7 present the results of the economic analysis of LIMB and FGD for retrofits. Note that for intermediate sulfur levels of 1.92 percent, LIMB is consistently more cost effective than FGD in the categories of cost per ton of SO_2 removed, total capital requirements, and levelized revenue requirements. For higher sulfur levels of 3.36, FGD has a slight edge in terms of cost per ton of SO_2 removed over LIMB when limestone and/or pressure hydrated dolomitic lime is used as the LIMB sorbent. This is due in part to the scenario chosen for FGD in that FGD would be retrofit to meet NSPS requirements. For FGD, the differential cost in capital requirement and levelized revenue requirement that occurs in going from 1.92 to 3.36 percent sulfur is offset to an extent by the increased SO_2 control.

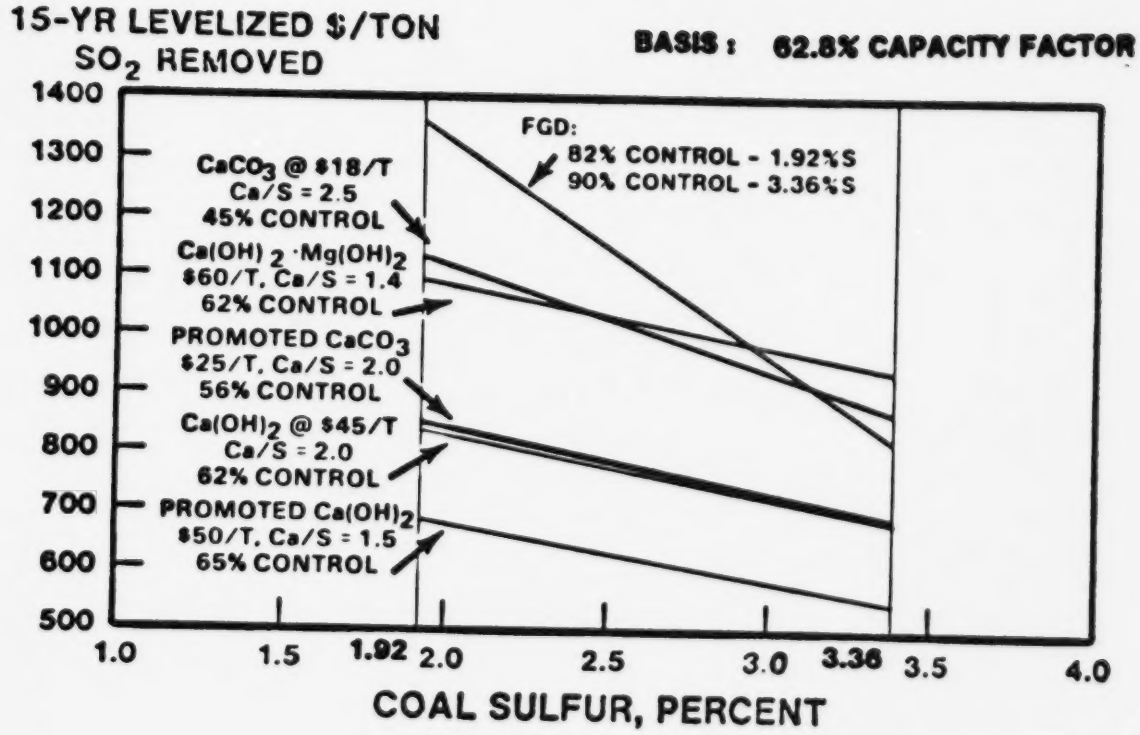

Figure 3. Comparison of SO_2 control technology cost; 300 MWe retrofit.

TABLE 7. COMPARISON OF COST COMPONENTS FOR RETROFIT LIMB AND FGD

Basis: 300 MWe Wall-fired Units at 62.8% Capacity Factor; 1985 Dollars

Technology	Sulfur, %	Sorbent	$/Ton SO_2	Total Capital Requirement, $/kW	15-Year Levelized Revenue Requirement, mills/kW·h[a]	15-Year Levelized Capital, mills/kW·h	15-Year Levelized Operating and Maintenance, mills/kW·h
FGD	1.92	$CaCO_3$	1359	210	17.30	6.10	11.20
LIMB	1.92	$CaCO_3$	1135	88	7.99	2.57	5.42
LIMB	1.92	$Ca(OH)_2$	844	79	8.14	2.30	5.84
LIMB	1.92	$Ca(OH)_2 \cdot Mg(OH)_2$	1101	89	10.61	2.59	8.02
LIMB	1.92	$CaCO_3$[b]	855	74	7.47	2.16	5.31
LIMB	1.92	$Ca(OH)_2$[b]	688	64	6.94	1.87	5.07
FGD	3.36	$CaCO_3$	829	239	20.22	6.97	13.25
LIMB	3.36	$CaCO_3$	874	107	10.81	3.11	7.70
LIMB	3.36	$Ca(OH)_2$	691	107	11.64	3.11	8.53
LIMB	3.36	$Ca(OH)_2 \cdot Mg(OH)_2$	942	122	15.87	3.55	12.32
LIMB	3.36	$CaCO_3$[b]	695	102	10.63	2.97	7.66
LIMB	3.36	$Ca(OH)_2$[b]	556	87	9.78	2.54	7.24

a. Includes levelized capital and levelized operating and maintenance charges.

b. Promoted sorbent.

For LIMB cases, a constant percentage control is assumed for these coals; consequently, on a cost per ton of SO_2 removed basis, LIMB's cost advantage relative to FGD diminishes for limestone or pressure hydrated dolomitic lime. However, LIMB continues to exhibit an economic advantage when $Ca(OH)_2$, promoted $Ca(OH)_2$, or promoted $CaCO_3$ is used as the sorbent. Note also that LIMB consistently shows an advantage over FGD in terms of total capital requirement and is always more than $100/kW cheaper.

Figure 4 and Table 8 present the results of the economic analysis of LIMB and FGD for new units meeting NSPS. Here, LIMB exhibits a significant economic advantage over FGD with the low sulfur coal. With intermediate sulfur levels, LIMB continues to be about 20 to nearly 50 percent lower in cost per ton of SO_2 removed than FGD. Table 8 illustrates that, for LIMB, the total capital requirement is consistently at least $100/kW less than FGD. For LIMB, the cost per ton of SO_2 removed is significantly affected by sorbent cost as reflected in the line representing the pressure hydrated dolomitic lime. $Ca(OH)_2$, both unpromoted and promoted, appears to be the sorbent of choice for NSPS applications.

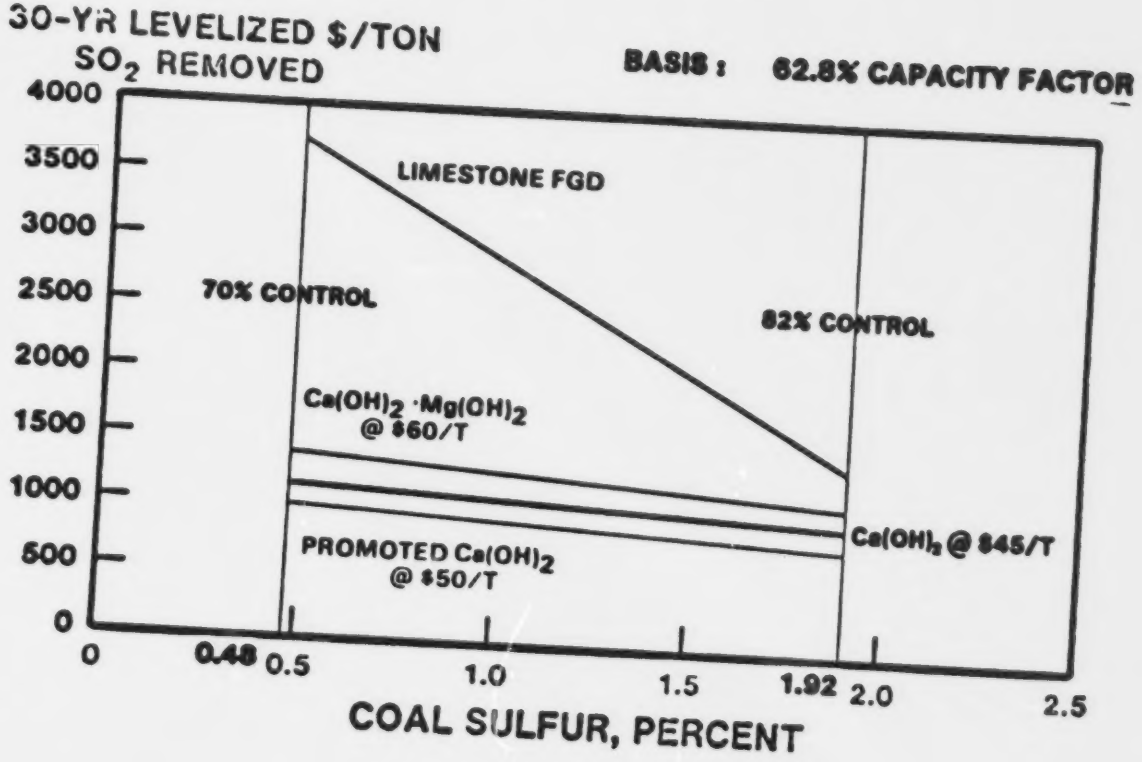

Figure 4. Comparison of SO_2 control technology cost; 500 MWe NSPS.

TABLE 8. COMPARISON OF COST COMPONENTS FOR NEW LIMB AND FGD

Basis: 500 MWe Wall-fired Units at 62.8% Capacity Factor; 1985 Dollars

Technology	Sulfur %	Sorbent	$/Ton SO_2	Total Capital Requirement, $/kW	30-Year Levelized Revenue Requirement, mills/kW·h[a]	30-Year Levelized Capital, mills/kW·h	30-Year Levelized Operating and Maintenance, mills/kW·h
FGD	0.48	$CaCO_3$	3715	158	15.97	4.39	11.58
LIMB	0.48	$Ca(OH)_2$	1134	19	4.87	0.54	4.33
LIMB	0.48	$Ca(OH)_2 \cdot Mg(OH)_2$	1366	21	5.87	0.58	5.29
LIMB	0.48	$Ca(OH)_2$[b]	961	18	4.13	0.49	3.64
FGD	1.92	$CaCO_3$	1377	170	17.53	4.73	12.80
LIMB	1.92	$Ca(OH)_2$	921	27	11.77	0.74	11.03
LIMB	1.92	$Ca(OH)_2 \cdot Mg(OH)_2$	1078	28	13.74	0.79	12.95
LIMB	1.92	$Ca(OH)_2$[b]	761	30	9.69	0.82	8.87

a. Includes levelized capital plus levelized operating maintenance charges.

b. Promoted sorbent.

An examination of Tables 7 and 8 shows that both processes are O&M intensive but, as a percentage of the total levelized revenue requirements, FGD is slightly less O&M intensive. This results because of FGD's lower sorbent cost and somewhat more favorable sorbent utilization. Despite this, LIMB has overall cost advantages that for many applications appear favorable.

CONCLUSIONS

EPA's LIMB program is receiving national and international attention as evidenced from the number of inquiries received, especially in the past 2 years. These have come from domestic boiler manufacturers and utility companies in addition to foreign governments. The acid rain issue is an international problem, and cost effective solutions are being sought. LIMB technology can provide a means for significantly reducing acid rain precursors at reasonable cost.

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CONVERSION TABLE

To Convert From	To	Multiply By
Btu/hr	watts (thermal)	2.930711 E-01
degree Fahrenheit	degree Celsius	$t°C = (t°F-32)/1.8$
ton (short, 2000 lb)	kilograms	9.071847 E+02
gallon (U.S. liquid)	$metre^3$	3.785412 E-03
Btu	joules	1.055056 E+03
pound (avoirdupois)	kilogram	4.535924 E-01
$lb/10^6$ Btu	nanograms/joule	4.33 E+02